Elastic-Plastic and Fully Plastic Fatigue Crack Growth

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The objectives of the elastic-plastic and fully plastic fatigue crack growth (EPFCG) research effort are to develop analytical solutions and computer programs for predicting the fracture life of flawed metallic structures which experience appreciable plastic crack tip stresses. In order to achieve these objectives, work is being focused on research to develop the analytical solutions and crack growth algorithms, as well as software development to extend the capabilities of the NASA/FLAGRO fracture mechanics program.

The research effort for analytical solutions in previous years has resulted in a list of over 20 flaw geometries for which J Integral solutions exist. These elastic-plastic solutions include collected works from the Electric Power Research Institute (EPRI), newly developed solutions combining finite element results and the reference stress method (RSM), and derived solutions using the reference stress method for existing elastic solutions in NASA/FLAGRO. This year, a modified J-integral estimation scheme for cracks at notches has been developed and validated against finite element results. This technique combines the EPRI and RSM estimation schemes to allow computation of J from the linear elastic limit through to the fully plastic limit (net section yielding) for all crack depths.

Research efforts have also concentrated on crack growth algorithms which use the J solutions to assess flaw instability, fatigue crack growth, crack closure, and multiple loading conditions. Most of the research work in the past year has been on algorithms for crack instability of ductile materials. Analytical models were developed which account for the possibility of the combined effects of fatigue crack growth and ductile tearing during cyclic loading. Crack tip zones that experience consistent loading and environmental conditions are assessed with the memory model, while those which experience overload or material changes (toughness) are assessed with the loss-of-memory model. For load cycles that create crack driving forces in excess of the elastic-plastic fracture toughness (material capability), the memory model includes the effects of ductile tearing for a given load cycle (n) only if there is an increase in crack driving force over the previous load cycle (n–1). Otherwise, if there is no increase in crack driving force, then only fatigue crack growth is accounted for in total crack extension during a given load cycle (n). On the other hand, the loss-of-memory model includes ductile tearing for every load cycle which creates crack driving forces in excess of the material capability. These two models significantly extend the capability of flaw growth prediction beyond the brittle fracture assumptions of the past.

In addition to research, a practical tool for assessing real elastic-plastic fracture problems is being created through the extension of the NASA/FLAGRO computer program. Considerable progress has been made in programming the elastic-plastic capabilities for the following NASA/FLAGRO geometries:

- TC01: Through center crack subjected to tension.
- TC02: Through edge crack subjected to tension or bending.
- EC01: Embedded elliptical crack subjected to tension.
- CC01: Corner crack in a rectangular plate subjected to tension or through wall bending.
- SC01: Surface crack in a rectangular plate subjected to tension or bending.

Both through flaw geometries, TC01 and TC02 are complete and have been verified for the plane stress and plane strain RSM solutions. A failure algorithm for calculating critical loads and crack sizes, along with software modules for the other three flaw configuration solutions, is currently in work.

Chell, G.G.: “Fatigue Crack Growth Laws for Brittle and Ductile Materials Including the Effects of Static Modes and Elastic-Plastic Deformation.” Fatigue Engineering Material and Structures, vol.7, 1984, pp. 237–250.

McClung, R.C.; Hudak, S.J., Jr.; Bartlett, M.L.; FitzGerald, J.H.: “Growth of Surface Cracks During Large Elastic-Plastic Loading Cycles.” Fracture Mechanics: Twenty-Third Symposium, ASTM STP 1189, 1993, pp. 265–283.

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